Best Practices in Solar Operation & Maintenance

Green Power

INDEX

1. **Who we are?**
2. **EGP, how we work today within O&M**
3. **Maintenance strategy**
4. **Operational Efficiency and Diagnostic Analysis**
5. **O&M Innovative Solutions**
   - Solar cells optimizers
   - PID Solution
   - Drones for O&M
   - Digitalization / Big Data

Who we are?

We are the world's largest producer of renewable energy

Over 65 years of experience
Worldwide

More than 63,500 collaborators

30 countries
We speak from Spanish, Italian, English, Portuguese, Romanian, Greek and even Russian

+ 1,400 plants
You would need 4 whole years to visit each of them

2.1 million km of energy distribution
Able to turn the earth around 52 times

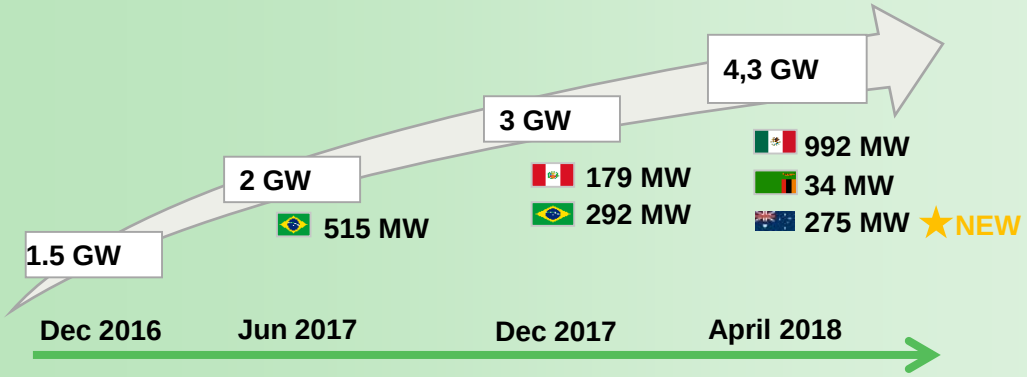
+42 GW
Generation capacity

enel
Green Power
+1.7 GW
INSTALLED CAPACITY
EGP
MÉXICO
675 MW
EOLIC ENERGY
52 MW
HIDRO ENERGY
992 MW
SOLAR ENERGY
4 PROYECTOS
UNDER CONSTRUCTION
4 PROYECTOS
UNDER EXECUTION
WILL ADD AN ADDITIONAL
1GW

Enel Green Power

How we work today within O&M

Installed capacity growth (GW)



Goal

Optimize **O&M Solar strategy, processes and activities** following **solar significant growth at global scale,** with **large plants** (>100 MW) in emerging solar markets for a total of **4,3 GW to be managed by 2Q 2018**

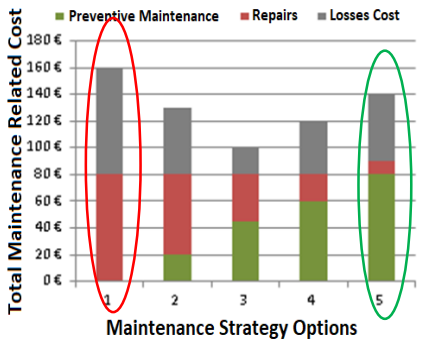
Project work-streams

- ✓ Definition of **optimized O&M Solar Strategy**
- ✓ **Operational Efficiency** and **Diagnostic Analysis** improvement
- ✓ **O&M Innovative Solutions & Practices** scouting, analysis and implementation
- ✓ **Training and professional growth** for "solar" colleagues
- ✓ **Dedicated IT Systems** to optimize solar plant maintenance
- ✓ **Communication** to boost involvement of all EGP colleagues on Solar

Maintenance strategy

Preventive maintenance

Preventive Maintenance activities are the core element of the maintenance services to a PV plant. It comprises regular visual and physical inspections, as well as verification activities conducted **with specific frequencies**. It is under the responsibility of the O&M contractor to prepare the task plan until the end of the contract



Corrective maintenance

Corrective Maintenance covers the activities performed by the Maintenance team in order to restore a PV plant system, equipment or component to a status where it can perform the required function. Corrective Maintenance include:

- ✓ **Fault Diagnosis**: also called troubleshooting to identify fault cause and localization
- ✓ **Temporary Repair**: to restore the required function of a faulty item for a limited time, until a Repair is carried out
- ✓ **Repair**: to restore the required function permanently

Extraordinary maintenance

Extraordinary Maintenance actions are necessary when major unpredictable events take place in the plant site that require substantial activities and Works to restore the previous plant conditions or any maintenance activity generally not covered or excluded from the O&M Contract.
Extraordinary Maintenance interventions are required for:

- ✓ Damages that are a consequence of a **Force Majeure event**
- ✓ Damages as a consequence of a theft of **fire**
- ✓ Modifications required by **regulatory changes**
- ✓ Other **upgrade** activities for perfomance improvement

Preventive maintenance

Predictive maintenance is a Condition-based maintenance carried out by evaluating **typical patterns** of **significant parameters** of plant components degradation. Predictive techniques help to determine the **condition of in-service equipment** in order to predict when and whether maintenance should be performed.

2 main activities to trigger:

1. DATA ANALYSIS ON MAIN EQUIPMENTS (Modules, Inverter, transformers)

2. TECHNICAL ISPECTIONS

Routine -> embedded in the Maintenance Plan

On Condition -> on main equipment

*Operation & Maintenance, Best Practices Guideline/ verison 2.0, 2018, Solar Powe Europe

Operational Efficiency and Diagnostic Analysis

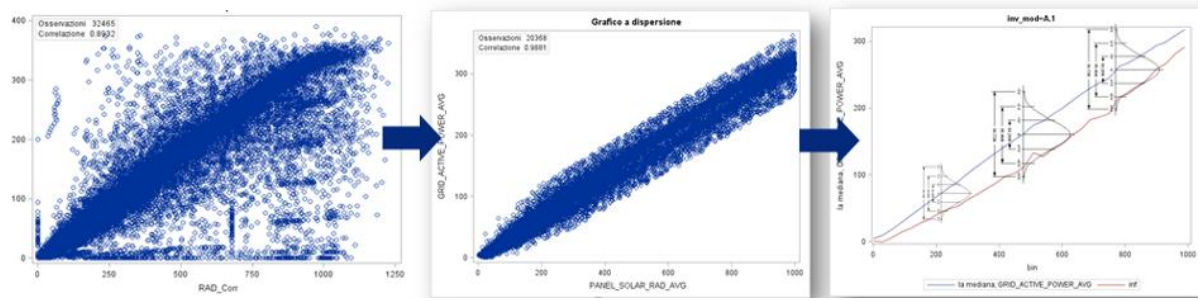
Algorithms developed in house on SAS platform

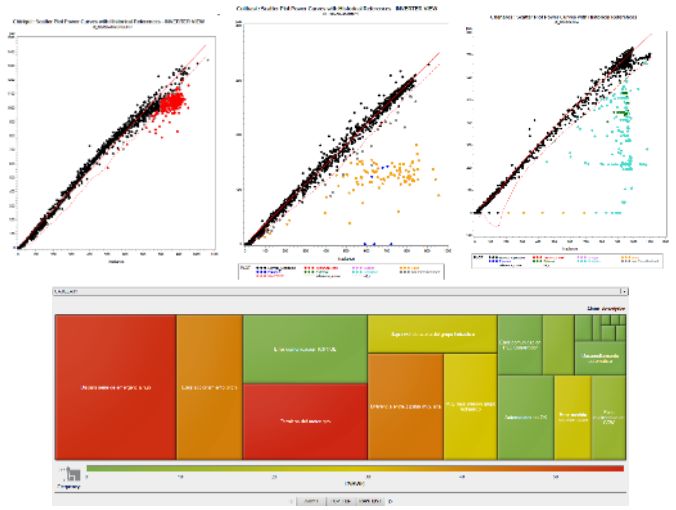
Relevant features

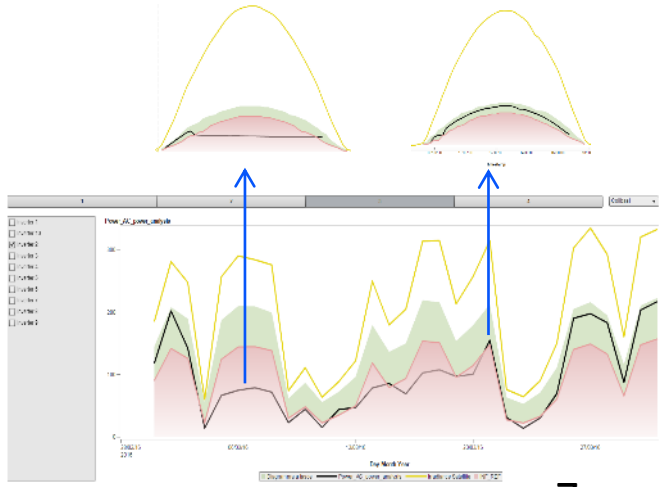
- ✓ **References Power Curves for single MPPT:** created through fully in-house developed algorithms based on neural network approach and statistical analysis on historical data and updated on yearly bases.

- ✓ **Operational Efficiency Analysis** for each MPPT to monitor the performance until the day before. Lost Production estimation and classification thanks to the Alarm Logbook from SCADA and Manual Logbook compiled by Supervisors on field.

- ✓ **Smart Reporting** and **Iterative Analytic Tool** developed in-house and available on-line and on personal mobile: **ICARUS**



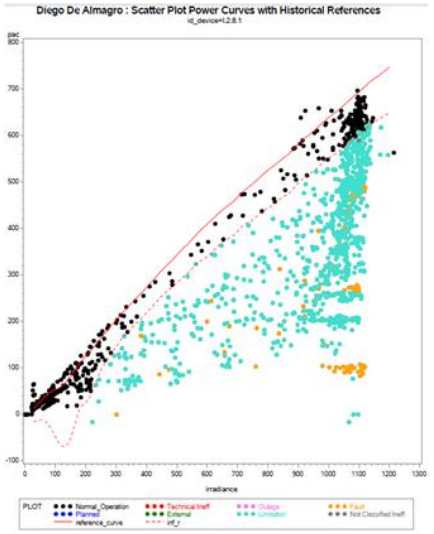




Operational Efficiency and Diagnostic Analysis

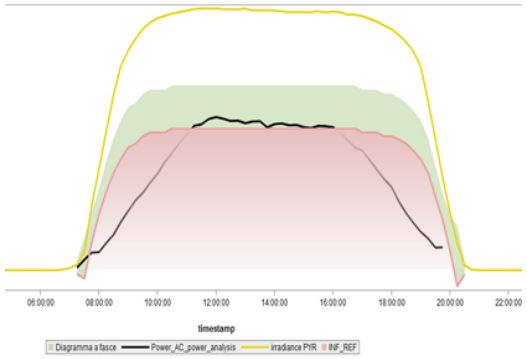
Examples Unavailability Events without an alarm

Tracker problems

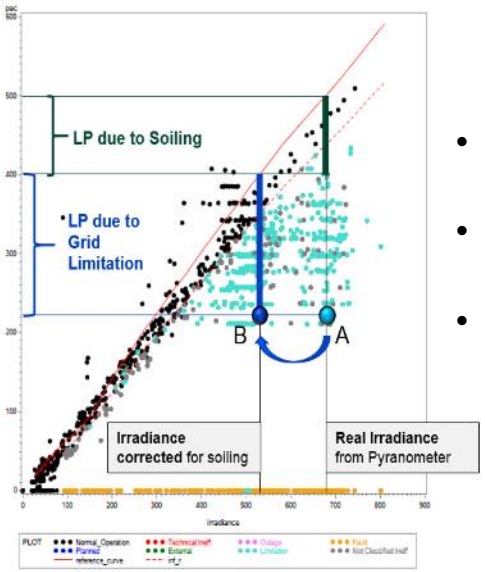


Automatic Allarm Trigger

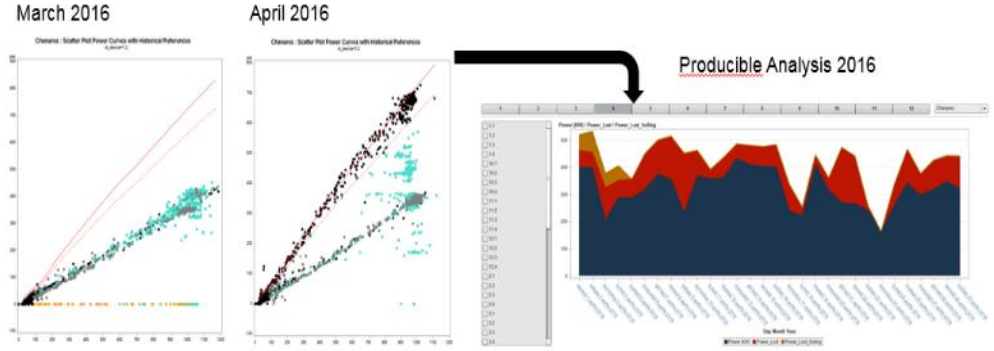
That consent to have a fast intervention on field in order to solve the problems.



Soiling Problems



- Daily acquisition of data from field and automatic processing;
- Evaluation of the Losses due to the dirty on panel;
- Cleaning optimization for the Country.



O&M Innovative Practices

Stream Overview

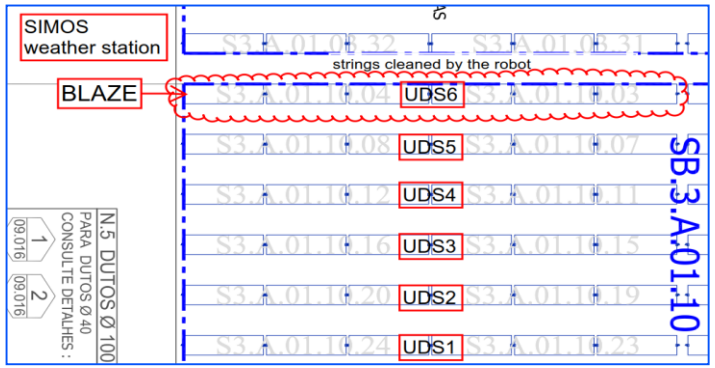
Goals	Activities carried out	Main results	Next step
Predictive Maintenance & Monitoring	• Preliminary Scouting and PoCs of **Predictive Monitoring** Solutions with INN • Completion of **onsite inspections within prototype project**	• Preliminary examples of **Predictive Platforms** (i-EM, M2D) • **Risk analysis and Catalogue** of main PV modules Failures • **Webinar** on PV Failures Detection. Involvement of EGP Solar Community	1. **Strengthening the synergies with <u>GRE Digital Hub</u>** for internalisation of Predictive mathematical models 2. Defining **the Amendment of** Contract for next tasks in 2018-2019
Innovative Cleaning	• **Testing of Anti Soiling Coating** and data analysis in **collaboration with INN** • PoC for dry-cleaning by Robots with INN	• **Cleaning Business cases shared within E&C Revolution Cleaning work stream** • Testing of **Robots** in **ITUVERAVA**	1. Identification of **Fully Automatic Cleaning** solution for O&M (if applicable, depending on specific site environments and PV plant design i.e. trackers)
Digitalization	• Preliminary **Gap analysis** in Data Lake • Gathering of **signals** database from LCR and WMR Cloud (Intellysinc)	• Check of signals in Cloud per **Inverter Manufacturer** • Preliminary analysis of signals from **MV system, trackers, DC section from LCR**	1. **Strengthening the synergies with <u>GRE Digital Hub</u> for unified Digital systems to be used in O&M activites**
Drones and Smart Glasses	• Scouting of **Drones suppliers with INN** • AR project with INN. Definition of the demo for **Smart Glasses at** PV plant in Europe	• **Business case for drones usage and Smart Glasses case shared within E&C Revolution dedicated work stream** • Release of **O&M Guideline for Drones inspections**	1. **Identification of solutions feasible to be applied in current Operation activities**

O&M Innovative Solutions

Innovative PV Cleaning: use cases

Project objective

Assessing the best innovative solutions for PV modules' cleaning to be applied in EGP PV Plants by using **customized cleaning robots**.



KPIs

- ✓ Self-Powered
- ✓ Being automatic or semi-automatic (operated with some, or totally without human intervention)
- ✓ Suitable to be mounted on solar tracking structures
- ✓ Without (or with very short) water usage for cleaning
- ✓ Suitable to guarantee a soiling recovery (dust, sand) ≥ 95%
- ✓ Deployed with a target price according to EGP economical requirements (e.g.

Highlights

- Technology reliability assessment performed by 2 different suppliers - operating tests performed in Europe for 2 plants on 5 robot per technology
- Ituverava (Chile) on field test.

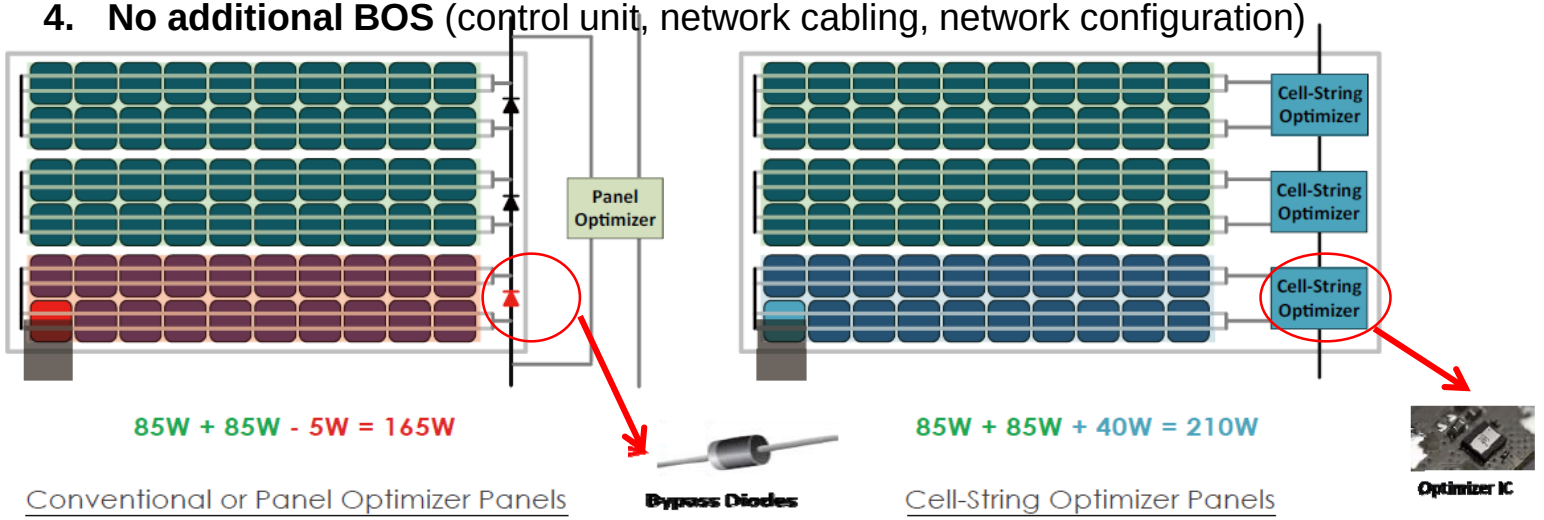
O&M Innovative solutions

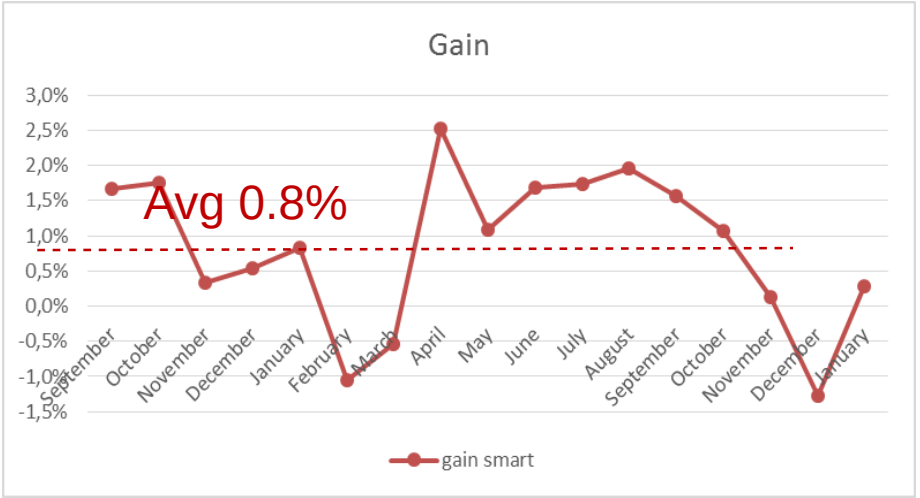
Solar cells optimizers

Smart modules replace the bypass diodes in the module with the optimizer chip in order to push the MPPT function deep into the PV system. Cell string optimizers allow to produce the **most energy possible** regardless of shading issues and mismatch, without the complexity of DC Optimizers and with simplified system design, improving also the reliability of the modules .

Advantages

1. **Increase energy yield** (each cell string delivers maximum power at the best current)
2. **Increase ground coverage and improve land utilization** (allows 10%-20% tighter row pitch at the same energy production per panel)
3. **Higher reliability**: Minimize power degradation over the panel and eliminate hot spots
4. **No additional BOS** (control unit, network cabling, network configuration)



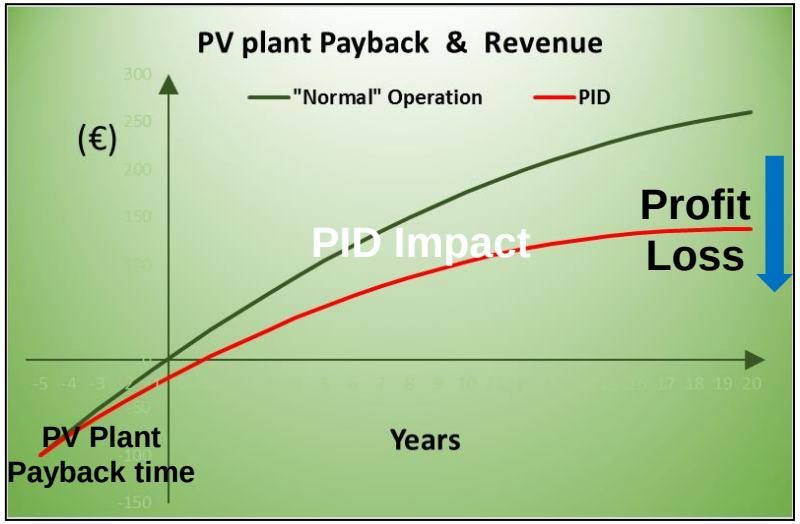


Results of La Silla project do not show significant values of energy increase

O&M Innovative Solutions

PID solution

- The PID - **Potential Induced Degradation** - is a specific Failure Mode occurring at **PV Modules** and leading to a **Performance Degradation**. The combination of several environmental stressors, quality of PV materials and exposure to a negative voltage potential is responsible for its occurrence.
- When **PID affect** our PV plant, a lower yearly revenue will be obteined with a direct impact on our total financial profit. The impact of PID could be so strong to invalidate the investment.

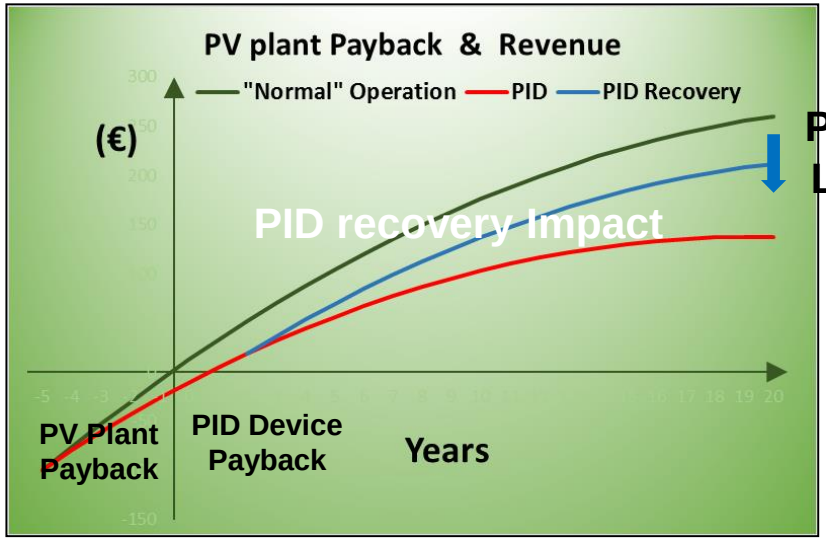


PID effect

Yearly Energy Production and Revenue reduction

PV Plant Profit Loss

PID = NET PROFIT LOSS



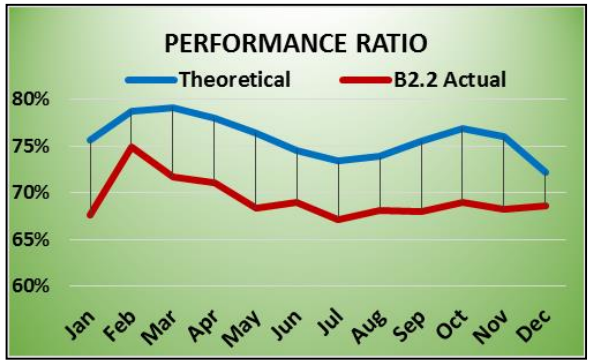
PID Recovery has to be considered as a corrective action in order to restore profitability of PV Plant investment

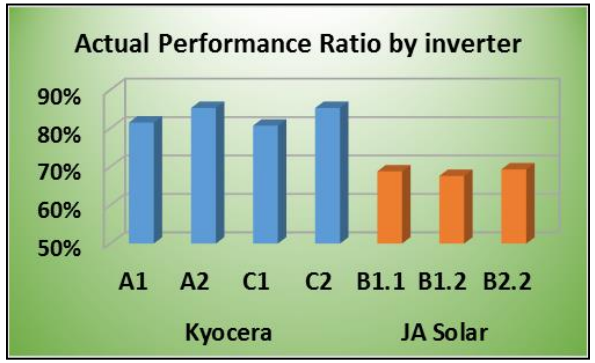
O&M Innovative Solutions

PID Solution

Stroussi PV Plant	
Nominal Power [MWp]	6.43
Yearly Energy prod [MWh]	9570
Yearly Energy Prod [MWh/ MWp]	1488

COD 24-01-2013
Operating LifeTime 27 years (30-35 years is typical value for EGP plants)





After 1 year opeartion actual PR lower (>5%) than theoretical one**.**

4.45 MWp (JA Solar JAP6230-235 crystalline modules) identified as impacted by **reversible PID**.

On going activities

Three different PID recovery technical solutions are under evaluation:

- Grounding Kit by constructor Installed in January 2016
- Two differentes PID Commercial Device in December 2017/April 2018

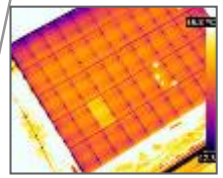
PID recovery benefits

PID Recovery loss of yearly Energy Prod (x MWp) = **5%**
PID recovery Time (months) = **6**

O&M Innovative Solutions

Drones for O&M

- Aircrafts that can be **remotely controlled** or **fly semi-autonomously** through software-controlled flight plans, working in conjunction with global positioning system (GPS)



New and **innovative technique** to **reduce costs** and **timing** of **operation**, **maintenance** and **construction activities**

- Utilized in **multiple industries**, driven by a growing need to **improve productivity** and **efficiency** via automation. Global **market revenue** is estimated to reach **$6.66 bln by 2020**

Substitute human workers during inspections, **reducing risks** related to people operating at height and confined areas

- Able to perform a **variety of tasks**, most often involving **imaging** or **payload-bearing** capabilities, leveraging on **precision robotics, computer vision,** and **artificial intelligence technologies**

Support security activities through **automatic anti-intrusion inspections**

Applications

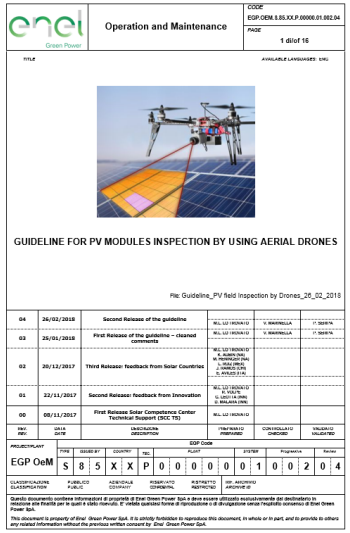
O&M Innovative Solutions

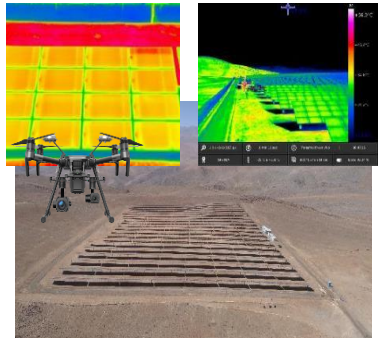
Drones for O&M

Highlights

The Aim of the project is the development of **Fully automated System for PV Inspections and data acquisition & reporting allowing to**

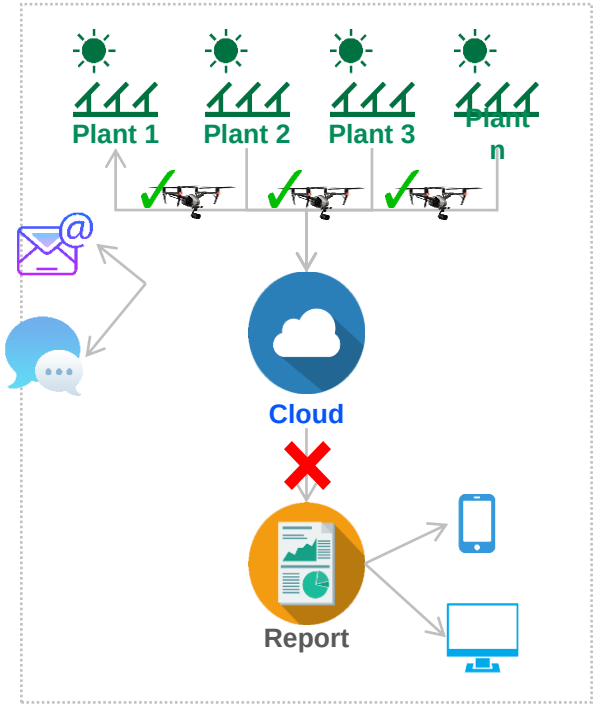
- **OPTIMIZE STANDARD PV INSPECTION** (up to 4MW/day of 4 hours covered with drone flight, 30' battery VS. **2%/plant** only with manual inspection)
- **REDUCE COSTS** of PV Manual Inspections





Use case description

- Permanent robotic system that includes drones that are **autonomous**;
- Exploits **satellite imagery** to locate the building site of a new plant;
- Monitor the status of the plant while it is under **construction**
- Totally **automatic and radiometric images analysis** of the PV field
- Verify the potential value for EGP using **Big Data approach** and define KPI parameters of interest that can both drive action planning by means of Actions to Solve (e.g. Decision Support System).
- **Hotspot failure** detection

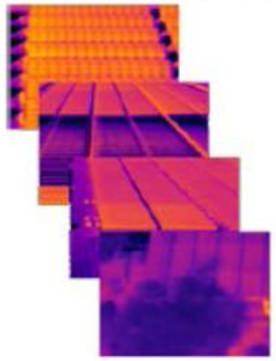


O&M Innovative Solutions and Practices

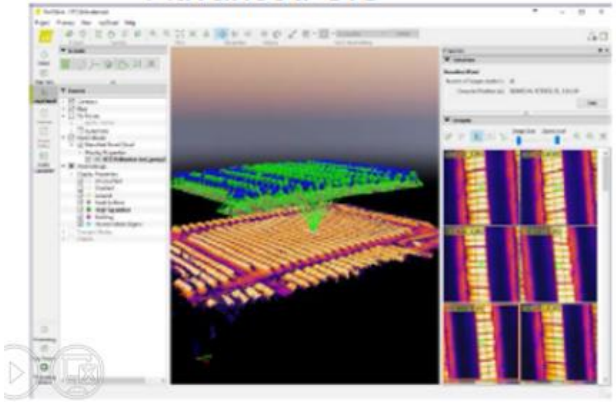
Business Case: USA

Drones are a catalyst for digital workflows

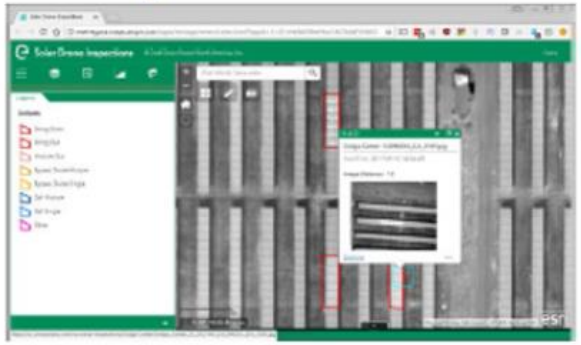
Autonomous Drone Imagery



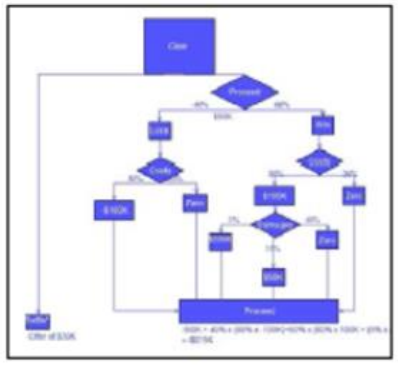
Advanced GIS



Rapid Defect Detection

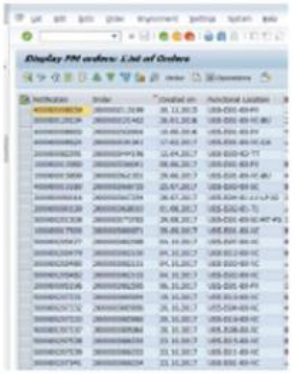


Automated Work Orders



Connected Digital Workforce

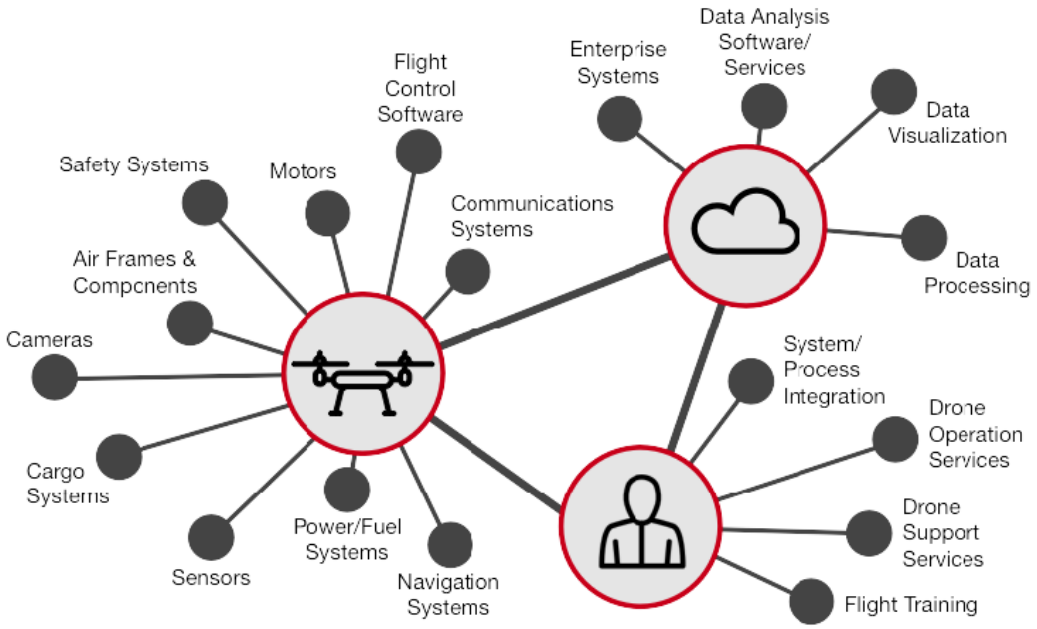
SAP Integration

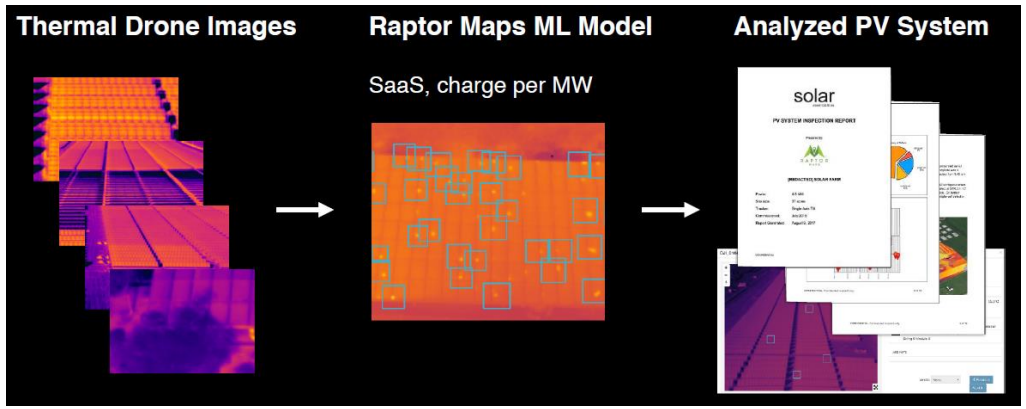


In-Field Mobile Apps

O&M Innovative Solutions and Practices

Business Case: USA





Combining these 2 capabilities for Innovate Mass

- Machine learning (ML) analytics for PV installations is a launched product
- Previously built drone-mounted and fixedmount thermal ML systems with onboard computing

Already working with EGP-NA partners in the field

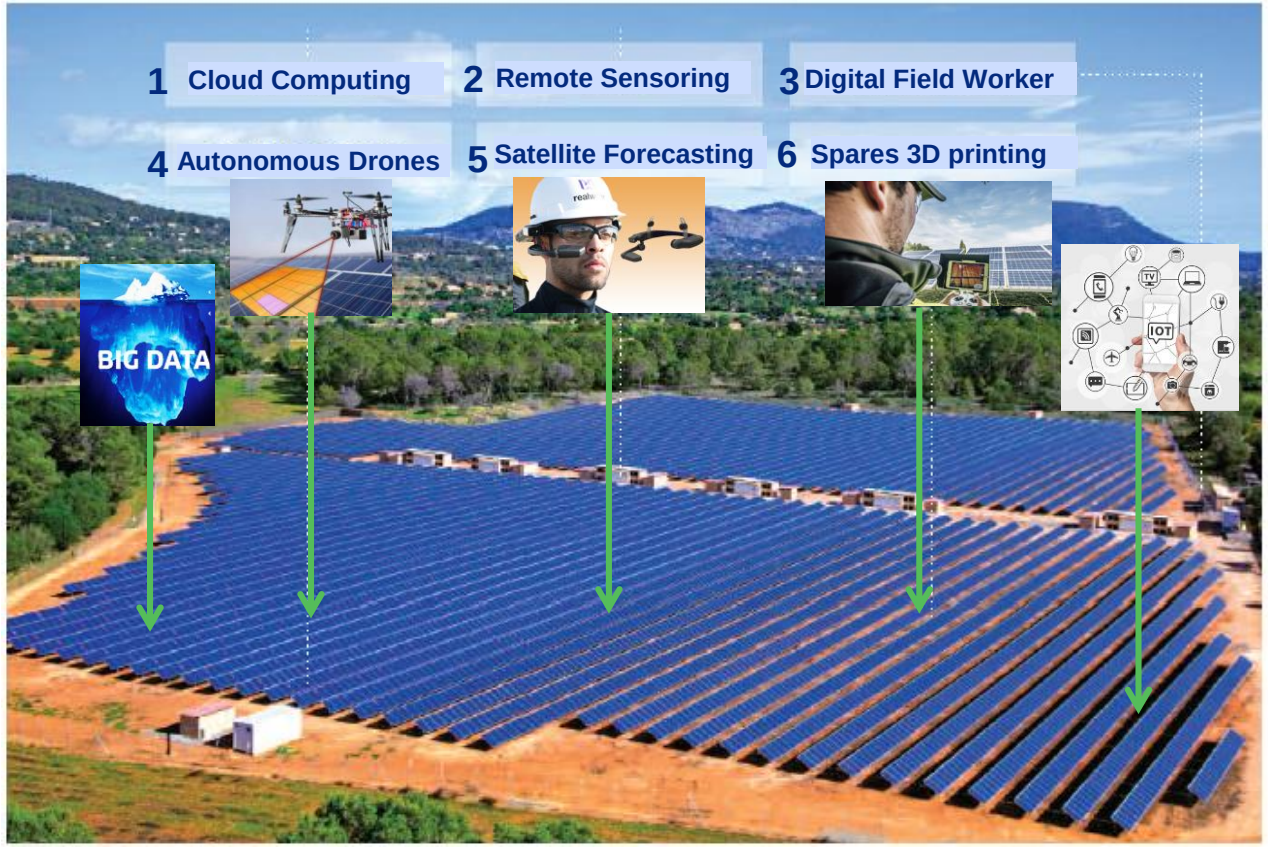
Environment

Restore 1.5% of lost capacity. Equivalent to removing 35,000 cars from the road per GW of installed solar.

Lower O&M cost for PV systems, making solar more competitive.

O&M Innovative Solutions

Digitalization



Source: Solar Power Europe Guideline, 2017

➢ Solar Digitization…What for?

- Reducing the Technical Risks
- Increasing Efficiency, Safety and Sustainability
- Reduction of Operational Costs
- Increasing of Solar Assets Lifetime

➢ Solar Digitization...How?

1. ***Cloud Big Data Computing*** with using Industrial Connectivity Data Platforms and Predictive Patterns-components specific to manage Plant Data and reduce emergency and periodic site visits

2. ***Remote Sensor & Control***. IoT, 5G and wireless communications, embedded test electronics and data analysis can help diagnose faults remotely

3. ***Digital Field Workers*** using mobile and AR/VR technologies such as Smartphones and Smart Glasses to assist effectively O&M activities in a safer way;

4. ***Autonomous Drones*** equipped with on-board data analytics to visual imaging modules and status of other PV components and IR imaging monitoring and transfer those images to Big Data Cloud;

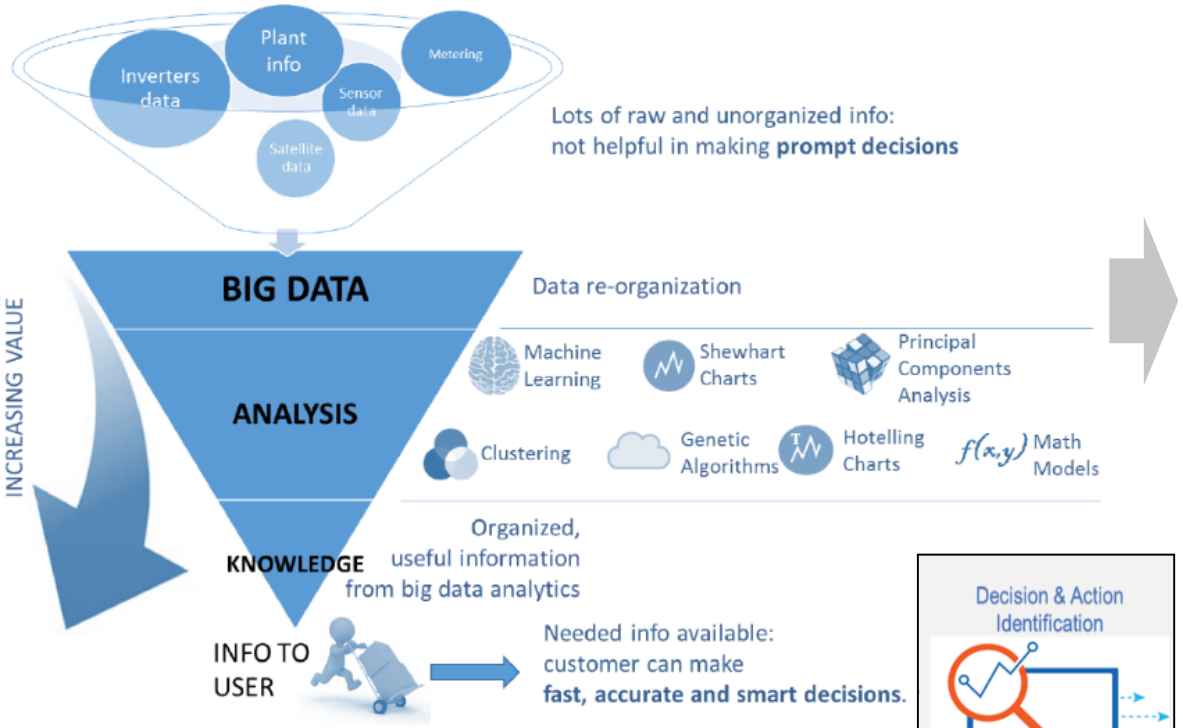
5. ***Satellite Forecasting*** service is the best practice for irradiance measurements and remote sensing to allow better-timed maintenance and also monitoring soiling accumulation for optimization of cleaning activities

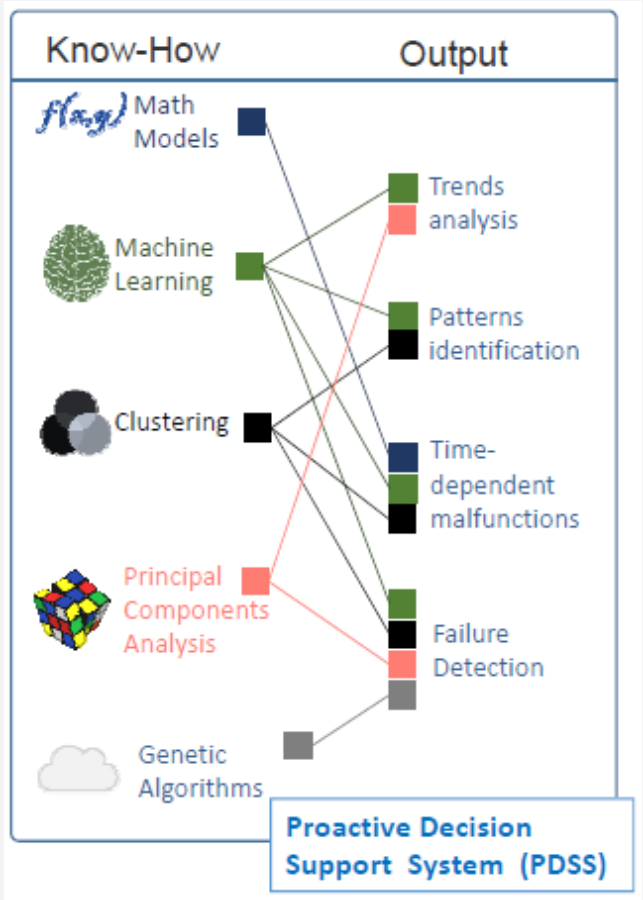
6. ***3D Printing*** to reduce spares in storage and theirs management and costs decreasing lead times

O&M Innovative Solutions and Practices

Digitalization: Proactive strategy

DRONES SWARMS:
Self-organized devices that autonomously detect failed modules and plant components





AUTOMATIZED O&M INTERVENTION
Exploiting plant robotized solutions for automatic maintenance work

O&M Innovative Solutions and Practices

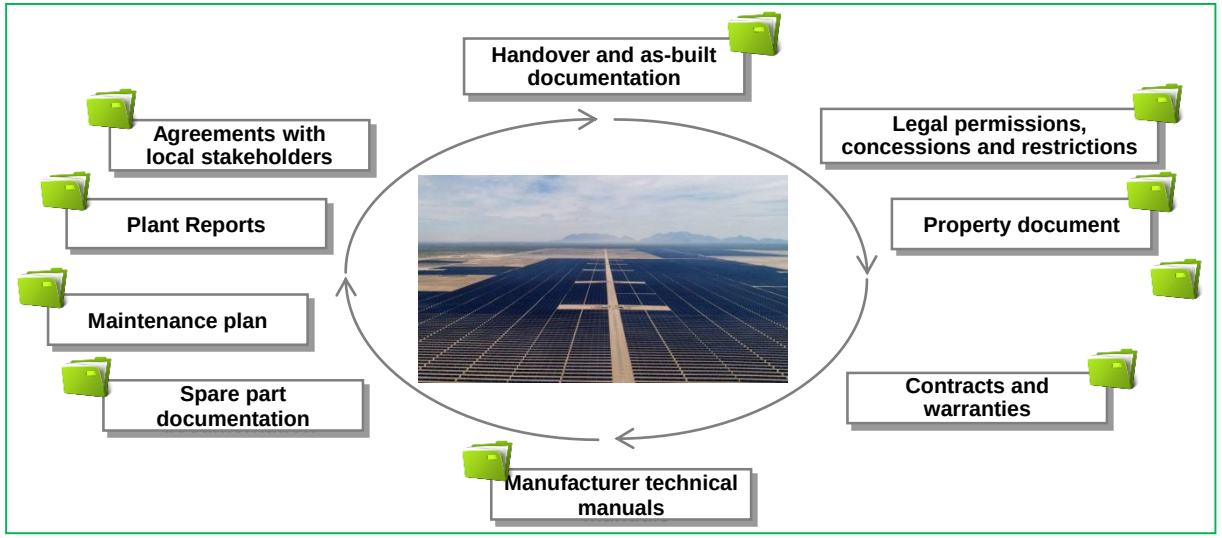
Digitalization

Plant documentation archived on CSK (Company Knowledge System) in cloud and available globally to all users O&M

Objectives

- Create a unique document management and collaboration **platform cross countries and functions**
- **Recuperate, store and digitalize all critical plant documents** - currently stored in local files systems, facilities and power plants - to guarantee access, improved archiving and retrieval of missing documentation.
- **Integration with other core systems** (i.e SAP, Archibus, MDM)

PLANT



Benefits

- **Global access** to a unique system **in cloud** (web application)
- All O&M Power plant **documentation** available and well **organized following IO 117**
- **Collaboration instrument** aimed at facilitating communication, project and knowledge management.
- Lever for **cross-functional & cross-country** business process integration & optimization

Documentation Management System (DMS)

Solar PV plant documentation is crucial for an in-depth understanding of design, configuration and technical details thereof. It is Asset Owner´s responsibility to provide those documents and if not available, they shoul, as best practice, be recreated at the Asset Owner´s cost. There are two important aspects related to the management of this information:

✓ Information type and depth of detail
✓ Management and control

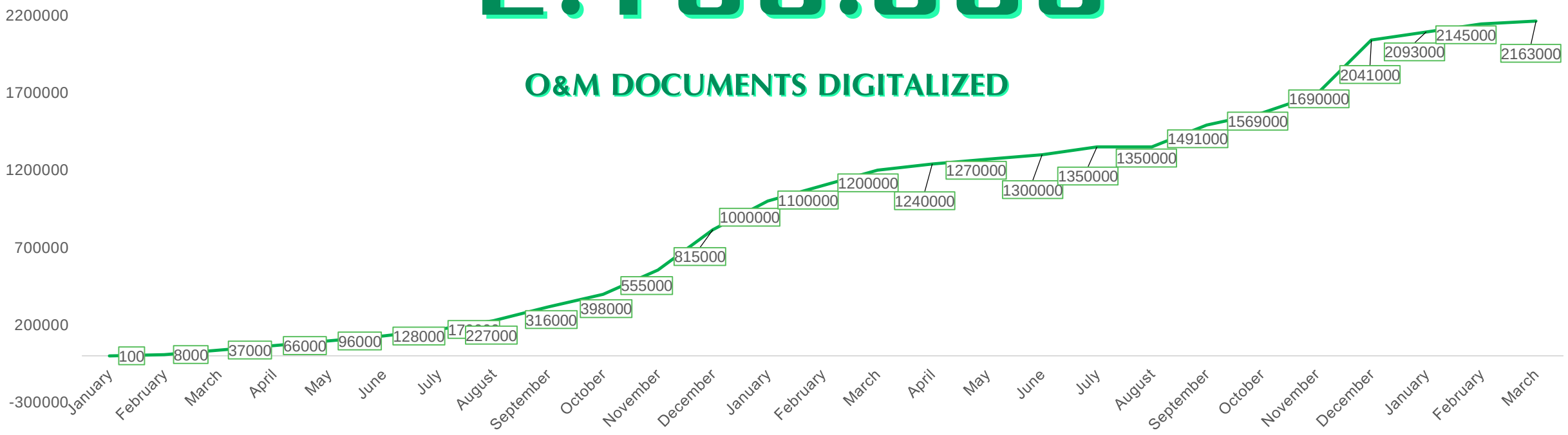
*Operation & Maintenance, Best Practices Guideline/ verison 2.0, 2018, Solar Powe Europe

O&M Innovative Solutions and Practices

Digitalization

2.163.000

O&M DOCUMENTS DIGITALIZED



Complete the implementation of the Quality Check-list process for the EGP Perimeter by 1H 2018

Complete the upload of Latam documentation and implementation of the Quality Check-list process by 2Q 2018

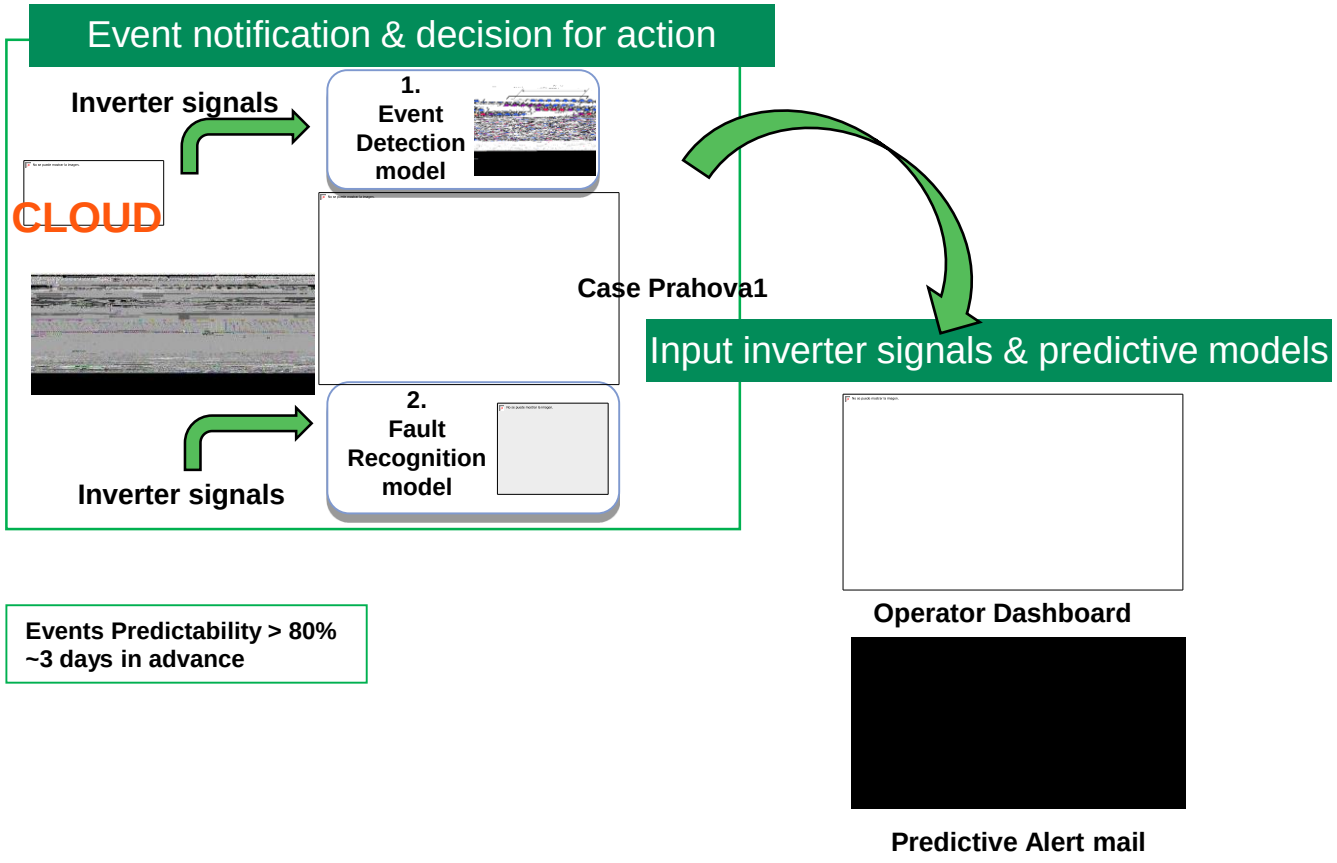
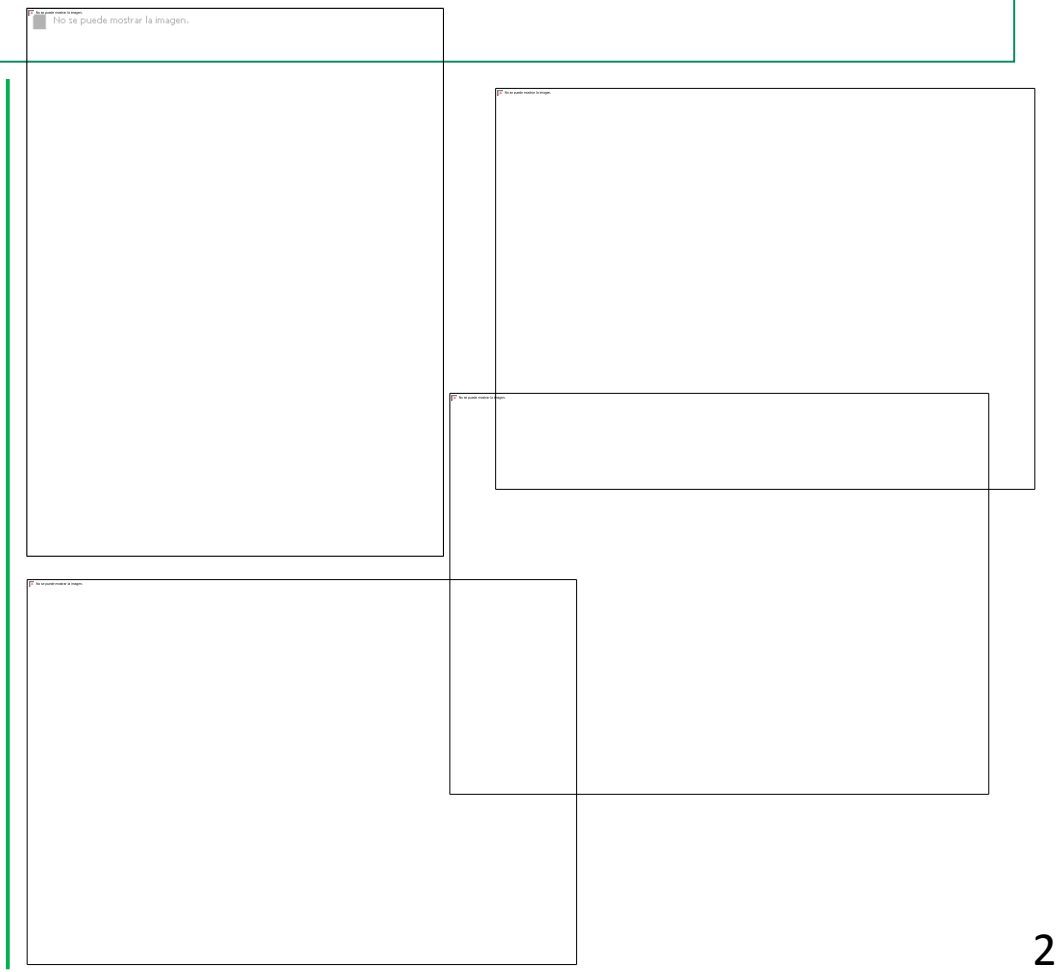
Completion of documents upload process with further ~200.000 documents by 2Q 2018

O&M Innovative Solutions and Practices

Big data analysis

The models approaches for the generation and **monitoring of predictive warnings** at inverter level have been investigated:

- ✓ **Event Detection** to predict inverter deviations from nominal behavior
- ✓ **Automatic Fault Recognition** to predict a specific class of faults (e.g. ground fault): automatic report generation
- ✓ **Short term prediction based on Cloud detection systems**
- ✓ **Mid term prediction based on BigData analysis** and recognized faults



Events Predictability > 80%
~3 days in advance